Importance of lunar geology in exploration and understanding our solar system

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Symbiosis of Science and Exploration

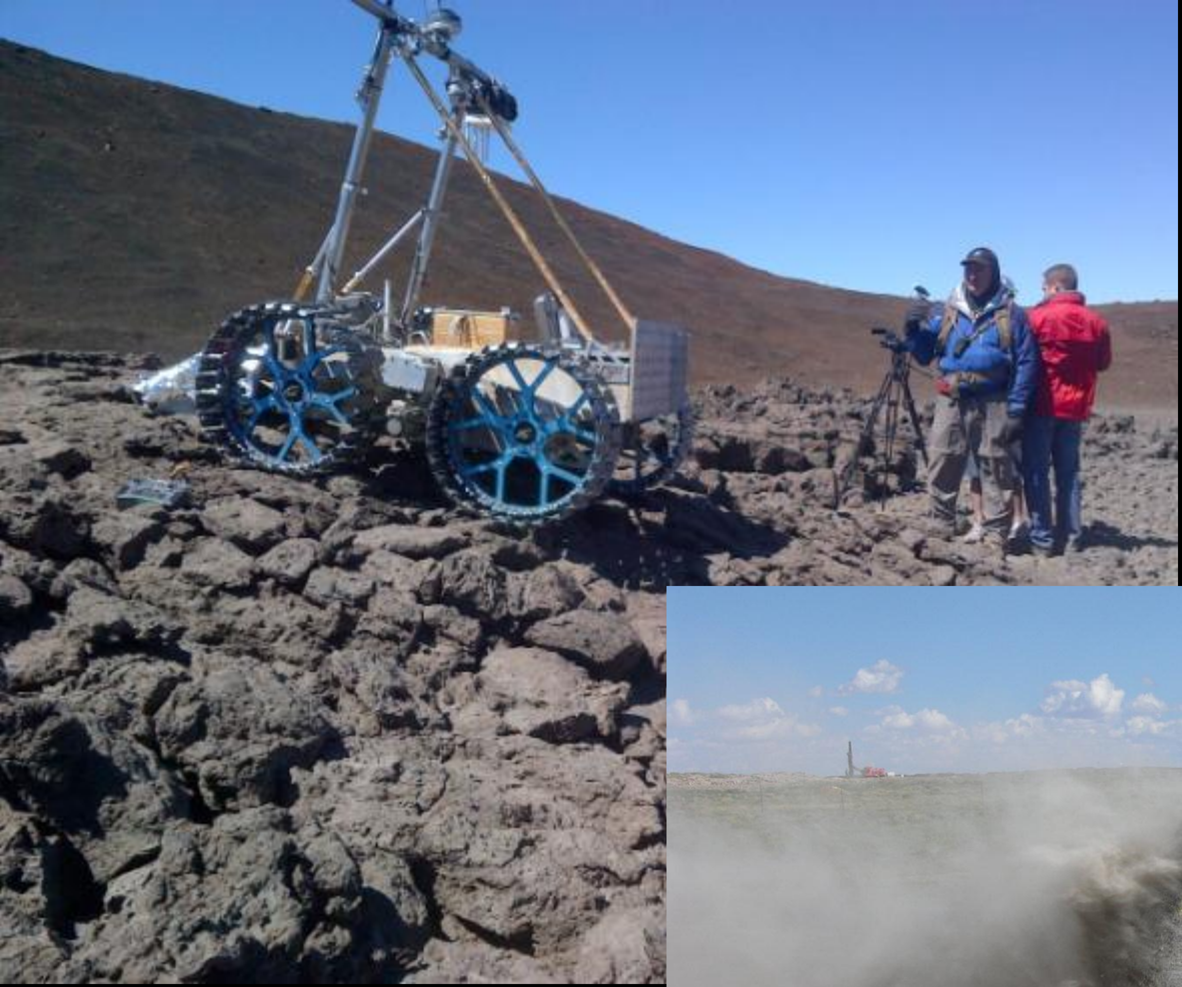
- Exploration / capability-driven

  ↑↓

- Science / question-driven

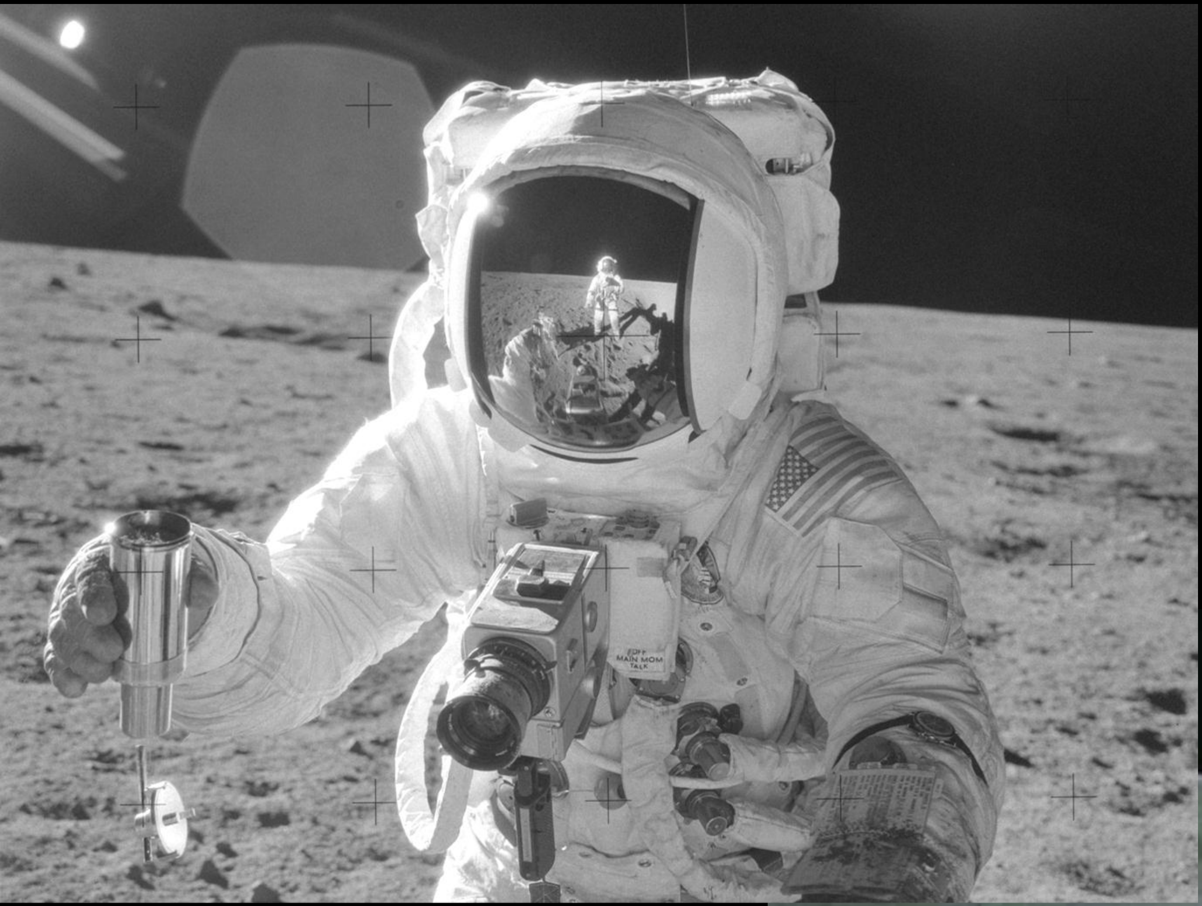
Complementarity of robotic and human explorers

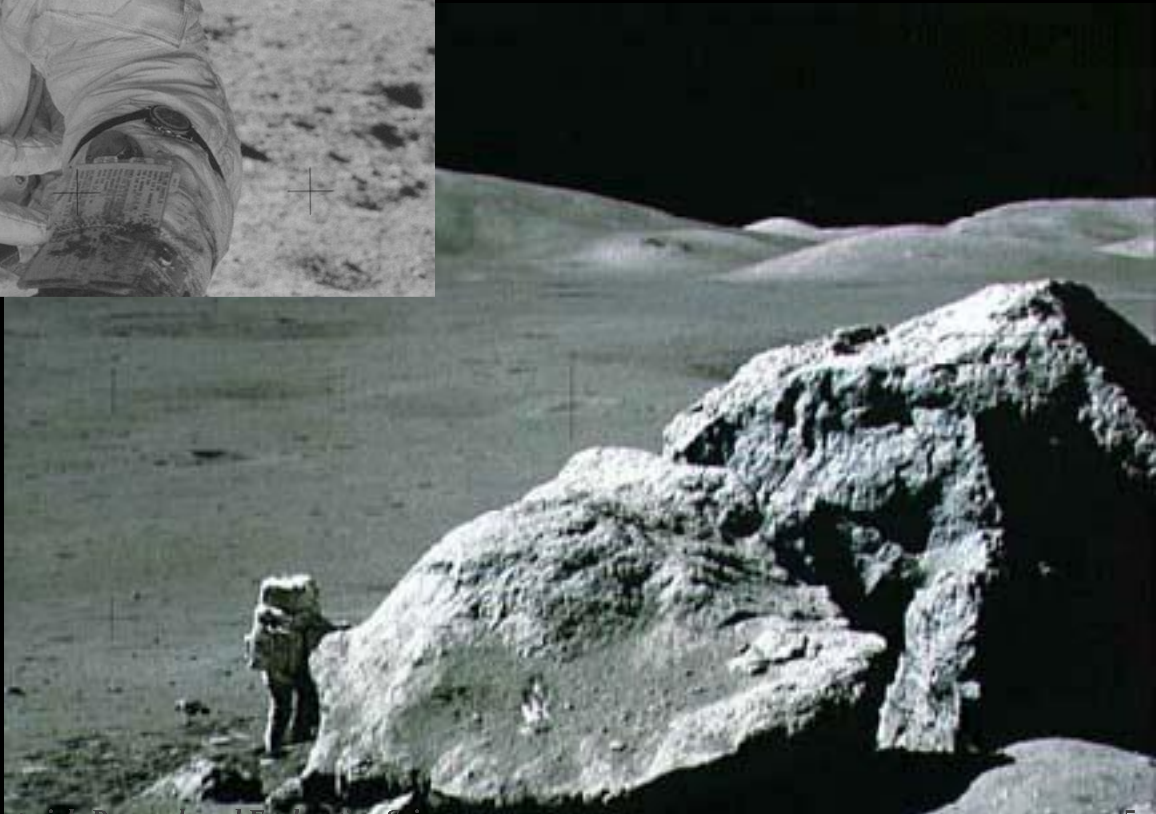
- The key to the successful and safe exploration of our solar system will be applying the proper balance of humans and robotic tools – in other words, using the right tool for the right task in the right location.



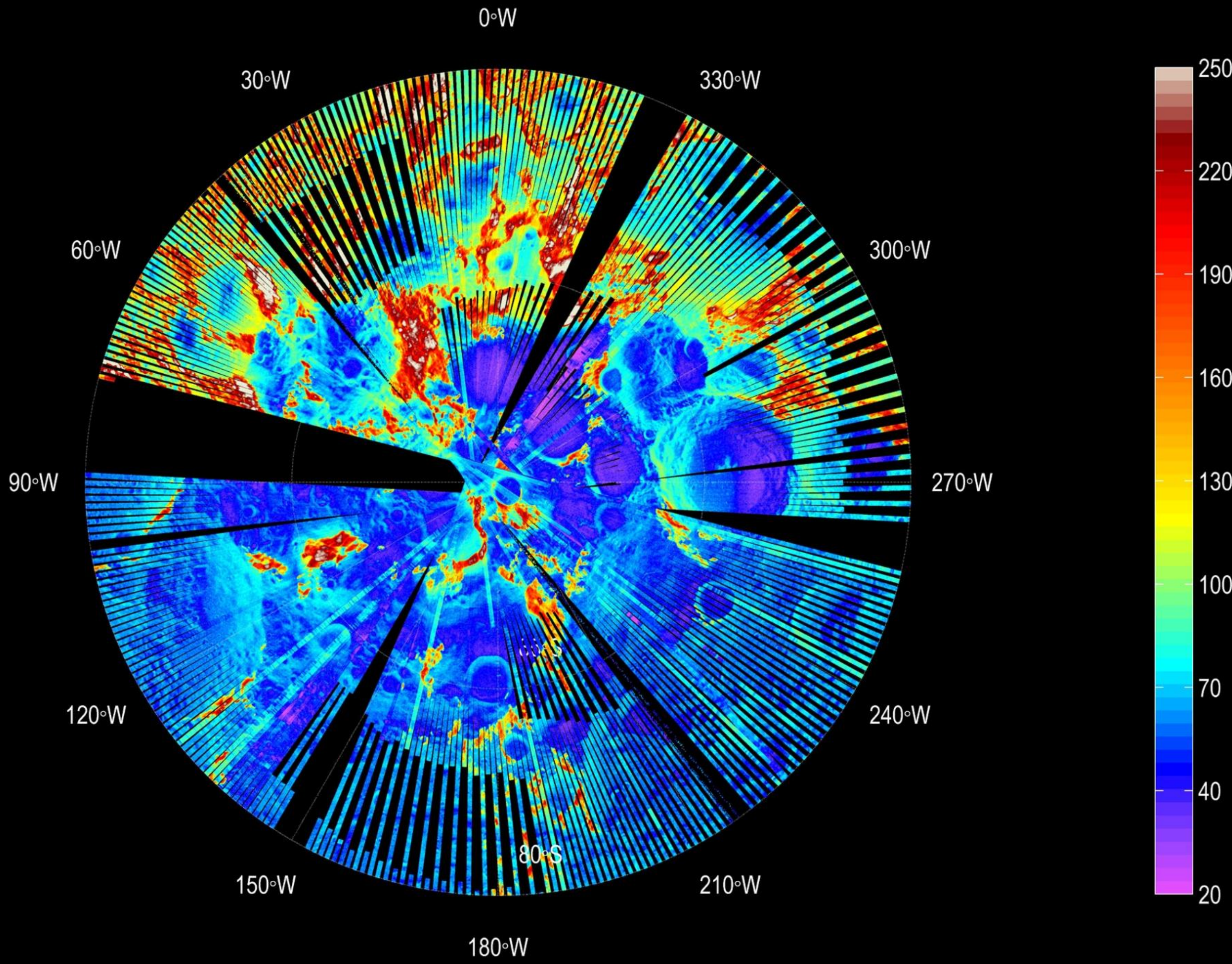
Juno II positioned to take measurement with Mössbauer Spectrometer at *MMAMA Science/Resource Prospecting Mission*

Centaur 2 at DRATS2010 fitted with digging implement



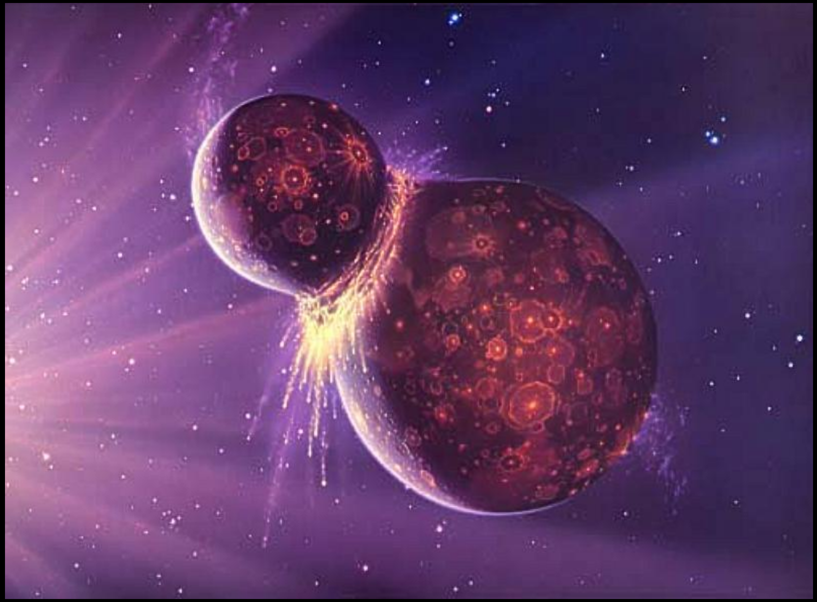


Diviner South Pole temperatures – late Winter



The Reach of Apollo

- Apollo samples have shaped our understanding of planetary bodies throughout the solar system
  - Giant impact origin of the Moon
  - Timescale of planetary formation and evolution
  - Our only direct insights into Early Earth History
  - The impact flux of the inner solar system.
  - The Nice model of Solar System evolution.
  - The role and origin of volatiles in lunar samples



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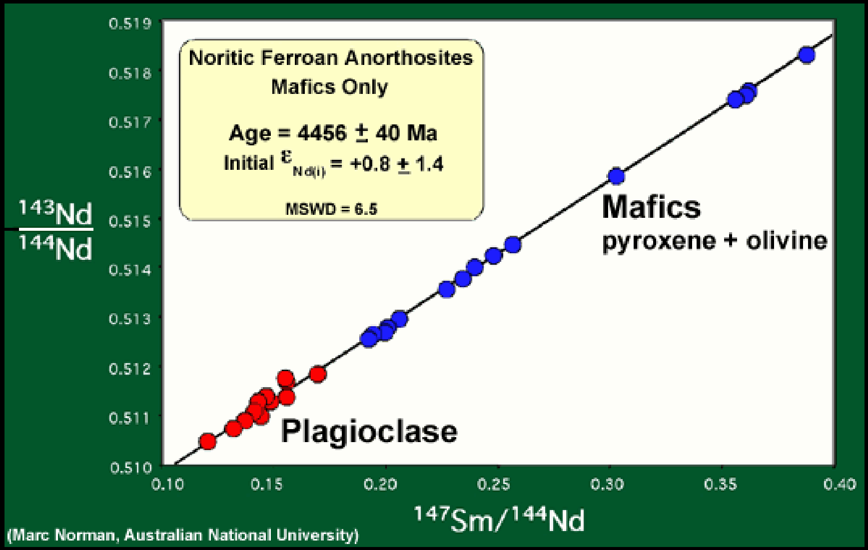
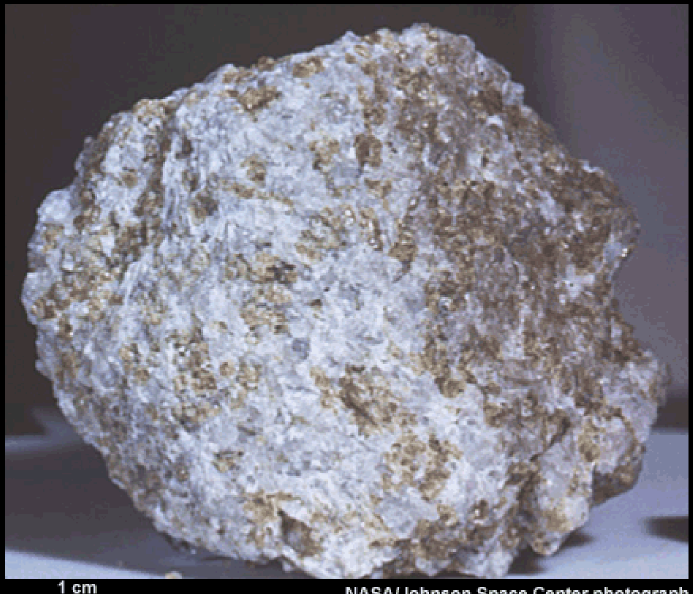


Apollo 17 troctolite 76535



NASA/Johnson Space Center photograph

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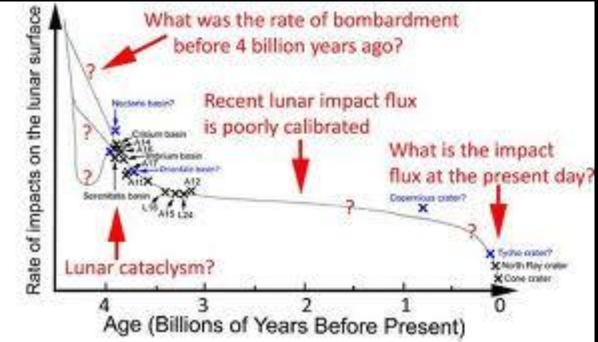

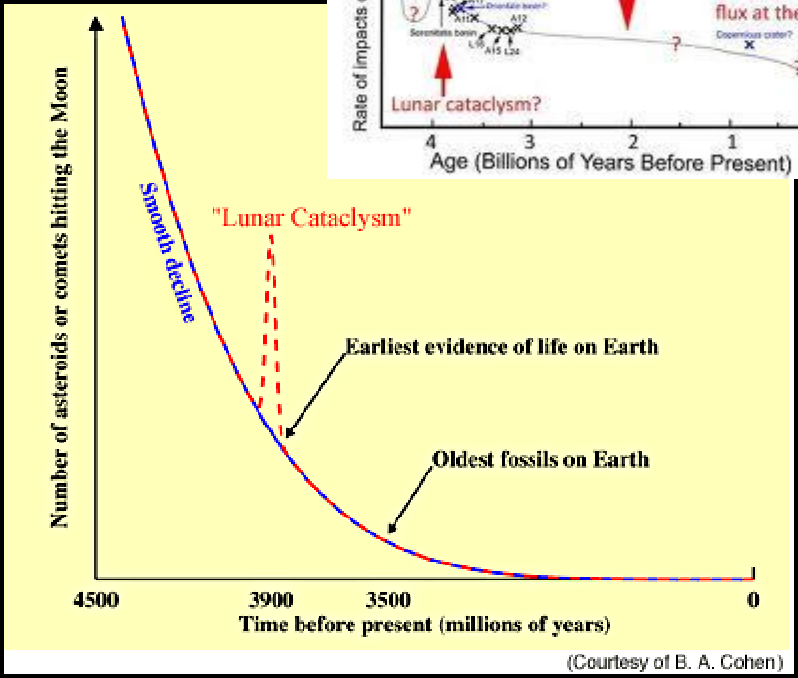

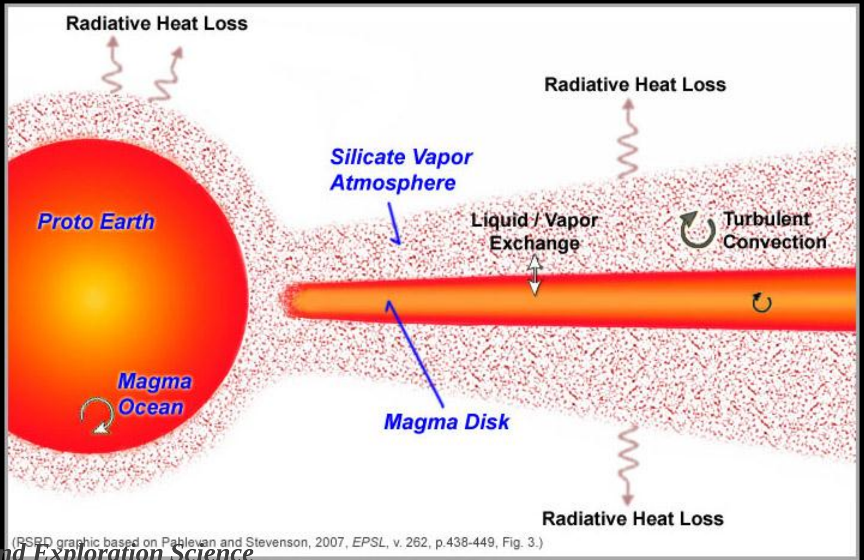

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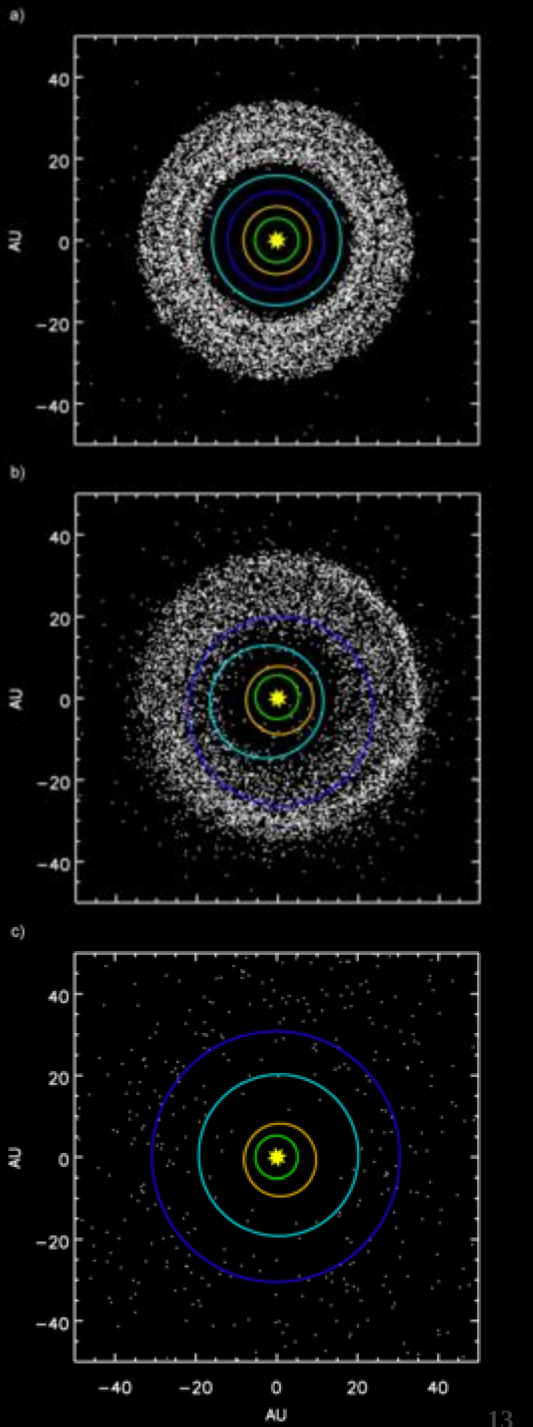

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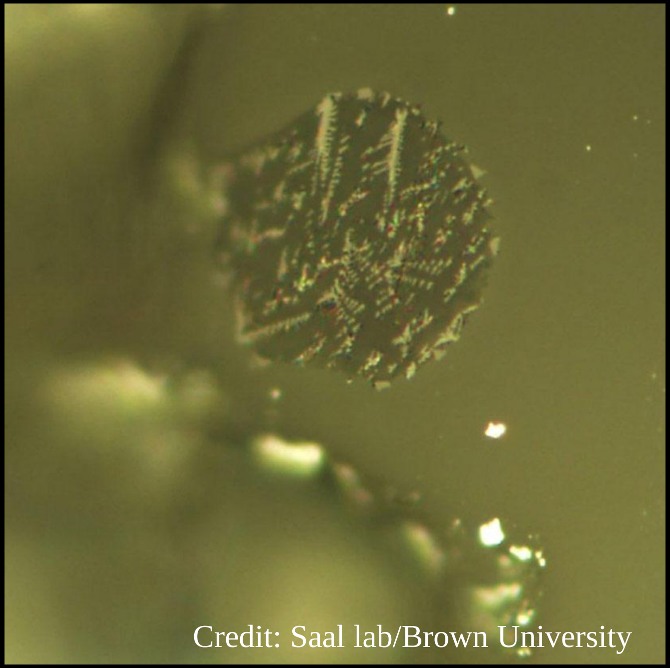


Credit: Saal lab/Brown University

Value of Lunar Geology – Historical Context

- What has been the value of lunar geology in it's historical context, particularly in terms of what we learned about the Solar System on the basis of doing geology on Apollo?

- Samples make a difference
  - How you collect them makes a difference…
  - The geologic context of the collected samples makes a difference…
  - Apollo samples vs. lunar meteorites
    - If all we had was lunar meteorites, we would not know the details about the geology of the Moon that we have developed with well-documented Apollo samples

Lunar Meteorites Complement Apollo Samples

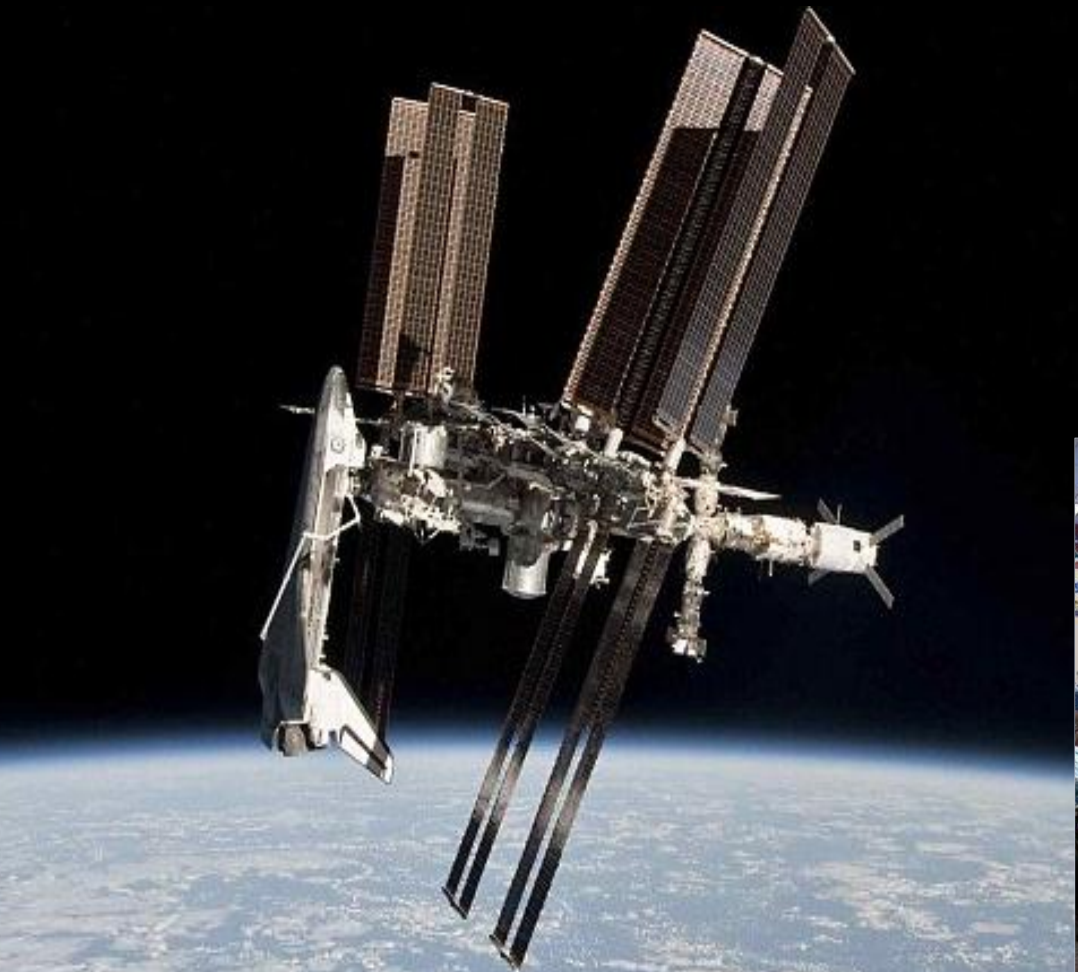
- ~78 lunar meteorites are important
  - These are random samples from ~40-50 locations on the Moon
  - Provide a better average overview of the Moon's crust
- They are also lacking in many respects:
  - No high-Ti basalt, granite, mafic plutonic rocks.
  - Only the most coherent samples survive (e.g., no soils), thus impact processes and solar wind info is lost.
  - Terrestrial contamination limits their usefulness in many cases (isotopic studies, volatiles)
  - ***Unknown source region!***

Capabilities needed for deep-space Exploration

- Stepping out into the solar system with humans require a few basic capabilities be developed
  - Living and working in micro-gravity
  - Living outside the protection of the van Allen belts (radiation)
  - Living and working in reduced gravity on another planetary surface
  - Operating for extended periods at long distances from Earth

Scripted Operations Philosophy

- Using the Moon to relearn the culture of exploration
  - Apply to other destinations → deep space



Igneous Rocks Classroom:Field Training Flow (mGEO1, mGEO2, mGEO3, mGEO5)

CLASSROOM TRAINING SUBJECT

Finding and establishing the size and geometry of subsurface features

Using igneous rocks for understanding deep planetary composition, processes

Direct observations of deep crustal material of formed very early in lunar history (Hadean age rocks)

Field mapping of volcanic & plutonic igneous rocks

CLASSROOM ACTIVITY

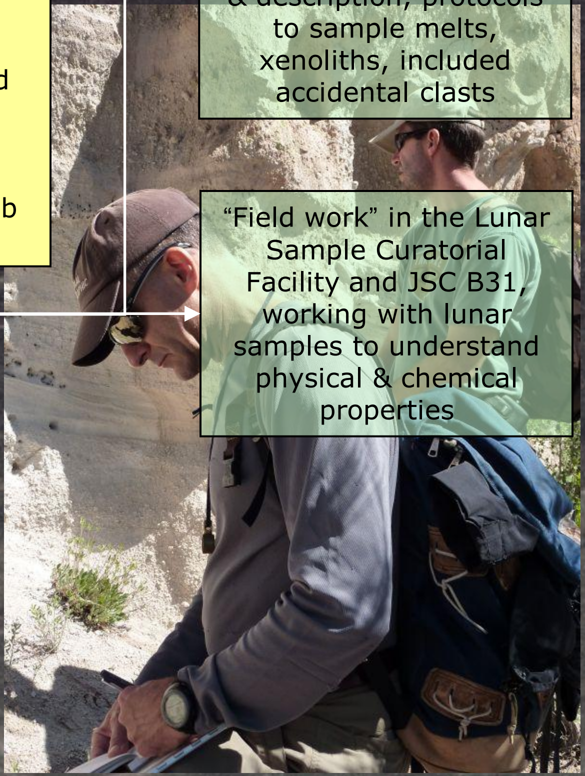
Basic geology training on igneous rocks, including:
- origin & use of igneous rocks to understand a planet’s thermal history
- rock types - basalts, ANT suite, ultramafic rocks
- both plutonic & volcanic rocks
- field relationships, including field mapping & description
- hand specimen identification & field description

Estimate 8 hours lecture, 8 hour lab exercises

FIELD ACTIVITY

Field work with volcanic & plutonic igneous rocks, including field relations, field hand specimen identification & description, protocols to sample melts, xenoliths, included accidental clasts

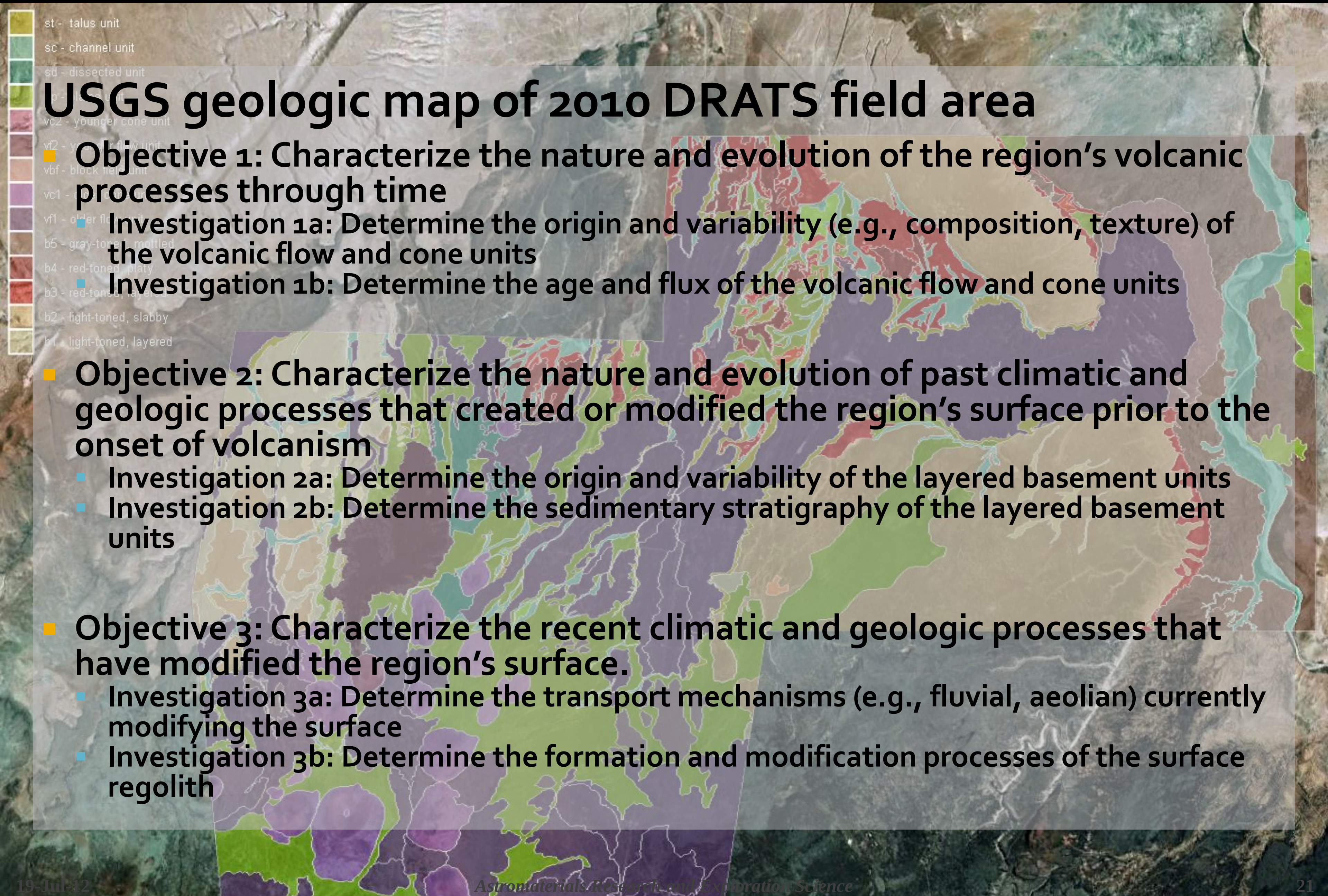
“Field work” in the Lunar Sample Curatorial Facility and JSC B31, working with lunar samples to understand physical & chemical properties



Investigation-based Operations Philosophy

- Context through precursor data
- Incorporate new technology / new techniques for dealing with communication delays
  - CAPCOM-forward
  - Text-based chat oriented communication
  - Automated integration of field notes to operational logs, maps, plans, and science objectives

Science Investigation-based Analog Exercises



USGS geologic map of 2010 DRATS field area

- Objective 1: Characterize the nature and evolution of the region's volcanic processes through time
  - Investigation 1a: Determine the origin and variability (e.g., composition, texture) of the volcanic flow and cone units
  - Investigation 1b: Determine the age and flux of the volcanic flow and cone units
- Objective 2: Characterize the nature and evolution of past climatic and geologic processes that created or modified the region's surface prior to the onset of volcanism
  - Investigation 2a: Determine the origin and variability of the layered basement units
  - Investigation 2b: Determine the sedimentary stratigraphy of the layered basement units
- Objective 3: Characterize the recent climatic and geologic processes that have modified the region's surface.
  - Investigation 3a: Determine the transport mechanisms (e.g., fluvial, aeolian) currently modifying the surface
  - Investigation 3b: Determine the formation and modification processes of the surface regolith

Analog Exercise (DRATS)

Mission and Science Operations Teams

Field Work and Operations Testing

Systems Performance Testing

The Moon as a Stepping Stone

- Use the Moon as a test-bed for mission operations and exploration techniques to reduce the risks and increase the productivity of future missions within the inner solar system
  - Crew autonomy
  - Human – Robotic partnerships
  - Communication protocols
  - Data handling / autonomous data analysis
  - Currency training

The Moon as a Stepping Stone

- Identify and test technologies on the Moon to enable robotic and human solar system science and exploration
  - Exploration infrastructure
    - EVA suits
    - Tools, Instruments, Analytical equip
    - Efficient (closed loop) life support
    - Engineering tests
    - Long duration power generation
    - …
  - In situ resource utilization

The Moon as a Stepping Stone

- Prepare for Missions to other Airless Bodies
  - Commonalities with Asteroids
    - Airless
    - Harsh radiation environments
    - Dusty environments
    - Surfaces contain regoliths
    - Large temperature swings between night and day
    - ISRU potential
    - Both contain volatiles and ices
  - Major differences
    - Gravity well
    - Rotation speed

Important Science left to Do

- A number of well-conducted studies (National Academy, NRC, etc.) have defined the high level open questions and objectives for future lunar geological research

- New discoveries
  - From current missions
  - From new techniques in analyzing old data/samples

- Geology alone does not completely answer all of the desired questions but the context it provides is the key to interpretation